(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 757 342 A3

(12) EUROPEAN PATENT APPLICATION

(88) Date of publication A3:
17.06.1998 Bulletin 1998/25

(43) Date of publication A2:
05.02.1997 Bulletin 1997/06

(21) Application number: 96305372.3

(22) Date of filing: 23.07.1996

(51) Int Cl.6: G10L 5/06, G10L 7/08, G10L 9/06, G10L 9/18

(84) Designated Contracting States:
DE GB

(30) Priority: 31.07.1995 US 509681

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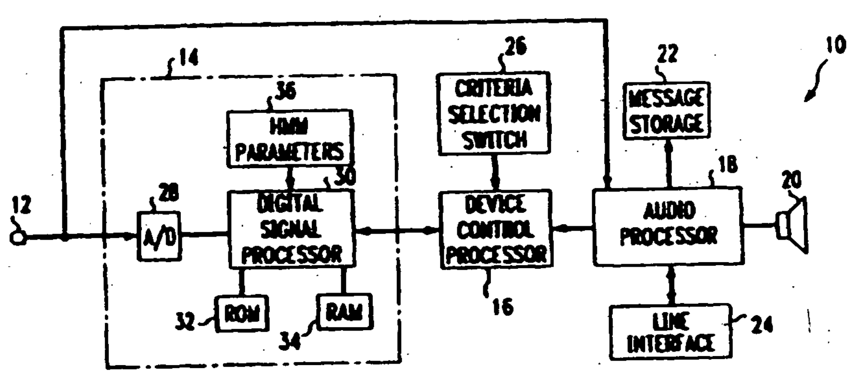
(54) User selectable multiple threshold criteria for voice recognition

(57) A method and apparatus for speech recognition in which a single criterion or set of criteria is selected manually by the user, from plural classes of recognition criteria. The stored classes of recognition criteria include a default class optimized for an average user in normal conditions, at least one class having a probability of recognition greater than said default class, and at least one class having a probability of recognition less than said default class. Accordingly, the user may select that class of criteria which provides the best results for him or her, as measured by greater accuracy (fewer false positive detections) or fewer instances of non-rejection.

An utterance is compared to one or more models of speech to determine a similarity metric for each such comparison. The model of speech which most closely matches the utterance is determined based on the one or more similarity metrics. The similarity metric corresponding to the most closely matching model of speech is analyzed to determine whether the similarity metric satisfies the criteria of the user-selected class. The present application has application to many problems in speech recognition including isolated word recognition and command spotting. Illustrative embodiments of the invention in the context of telecommunications instruments are provided.

FIG. 1



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EUROPEAN SEARCH REPORT

Application Number

EP 96305372.3

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.6)
X	EP 0311414 A2 (NEC CORP.) 12 April 1989 (12.04.89), fig. 1, abstract, claim 1, column 1, line 35 - column 2, line 26. --	1-5	G 10 L 5/06 G 10 L 7/08 G 10 L 9/06 G 10 L 9/18
A	EP 0060086 A1 (THRESHOLD TECHNOLOGY INC.) 15 September 1982 (15.09.82), fig. 1, claim 1, abstract, page 8, line 1 - page 11, line 21. --	1-13	
A	US 4319085 A (WELCH et al.) 09 March 1982 (09.03.82), fig. 1, abstract, claim 1. ----	1-13	

TECHNICAL FIELDS SEARCHED (Int. Cl.6)

G 10 L 3/00
G 10 L 5/00
G 10 L 7/00
G 10 L 9/00
H 04 M 1/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	30-03-1998	BERGER

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P0401)

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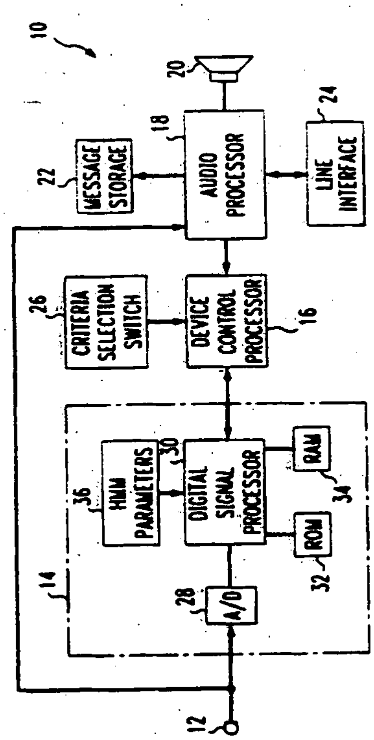

FIG. 1

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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present inventions relates to the field of speech recognition and, for example, to the detection of commands in continuous speech.

2. Description of the Background Art

Command spotting systems, which are responsive to human voice, are highly desirable for a wide variety of consumer products. In a telecommunications instrument, for example, typical operations such as on/off, transmit/receive, volume, push-button dialing, speech recognizer training, and telephone answering device functions may be readily achieved by monitoring an audio input channel and taking appropriate action whenever a specific utterance (the command) appears in the input. For each command to be recognized by the system, a statistical model such, for example, as a template or hidden Markov model (HMM) well known in the art, is maintained. The statistical model defines the likelihood that a given segment of input contains a command utterance.

During its operation, a conventional command spotting system continually generates conjectures or hypotheses about the identities and locations of command words in the currently observed input. Each hypothesis is tested against a respective command model and a score is generated for its respective likelihood. The score may be determined by, for example, conventional Viterbi scoring. If the score exceeds a threshold T, the hypothesis is considered as accepted and the action associated with it is effected. Otherwise, the hypothesis is rejected. The probability distribution of the score of either a correct or a false hypothesis depends on a variety of actors, including the speaker, the transducer, and the acoustical environment. A fixed threshold T is usually set sufficiently high to ensure, for the maximum number of users, an acceptably low false alarm rate over the whole range of expected operating conditions. Unfortunately, due to wide variations in user voice characteristics and environmental conditions, the selected threshold typically functions much better for some users than others.

Users having a low probability of exceeding the threshold may, on a regular basis, be ignored by the system. One technique for addressing the problem of frequently rejected users is directed to reducing the threshold level. Setting the threshold too low, however, typically results in an unacceptably high number of false positive hypotheses for average users.

SUMMARY OF THE INVENTION

According to the present invention, the abovementioned deficiencies of the prior art are avoided by a variable criteria speech recognition technique suitable for, among other applications, command spotting and isolated word spotting.

A recognition criterion or set of recognition criteria are selected manually (by the user), from among plural recognition criteria or sets of recognition criteria. An utterance is compared to one or more models of speech to determine a similarity metric for each such comparison. The model of speech which most closely matches the utterance is determined based on the one or more similarity metrics. The similarity metric corresponding to the most closely matching model of speech is analyzed to determine whether the similarity metric satisfies the selected set of recognition criteria.

Some of the recognition criteria serve to increase the threshold of recognition while others serve to decrease the threshold of recognition. In accordance with an illustrative embodiment of the present invention, users of a device employing the inventive speech recognition system and method are provided with the ability to select a set of recognition criteria that is to be applied to voice utterances. Illustratively, the selecting means may comprise a feature option or a switch setting. Selection of a recognition criteria set may be performed on a per user basis, a per command basis, a per command family basis, or a combination thereof.

The various features of novelty which characterize the invention are pointed out with particularity in the claims annexed to and forming a part of the disclosure. For a better understanding of the invention, its operating advantages, and specific objects attained by its use, reference should be had to the accompanying drawings and descriptive matter in which there are illustrated and described several embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The features and advantages of the present invention will be more readily understood from the following detailed description when read in conjunction with the accompanying drawings, in which:

FIG. 1 is a block diagram of an illustrative device configured to utilize user-selectable, multiple criteria speech recognition in accordance with the present invention;

FIG. 2 depicts a block flow diagram depicting the performance of speech recognition to provide a control interface for the illustrative device of FIG. 1; and

FIG. 3 shows a block flow diagram depicting the process by which a set of criteria are manually se-

lected by the user in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

For clarity of explanation, the illustrative embodiment of the present invention is presented as comprising individual functional blocks (including functional blocks labeled as "processors"). The functions represented by these blocks may be implemented through the use of either shared or dedicated hardware including, but not limited to, hardware capable of executing software. Illustratively, the functions of the processors presented in FIG. 1 may be implemented by a single shared processor such, for example, as a digital signal processor (DSP). It should be noted, however, that as utilized herein, the term "processor" is not intended to refer exclusively to hardware capable of executing software.

FIG. 1 presents an illustrative embodiment of the present invention which concerns a telephone answering device employing speech recognition. It is also contemplated, however, that the teachings of the present invention are equally applicable to any device in which a voice-operated control interface is desired. For example, the use of selectable multiple-threshold criteria for voice recognition in accordance with the present invention may be easily extended to the control of conventional home and business telephones, cordless and cellular telephones, personal data organizers, facsimile machines, computers (such as personal computers) and computer terminals.

In any event, and as shown in FIG. 1, device 10 includes a microphone 12 for receiving input speech from the user, a speech recognition system 14, and a device control processor 16 for directing the operation of the various functioning components of the device 10. In the illustrative embodiment, in which device 10 is configured as an answering machine, these components include an audio processor 18, a speaker 20, a message storage unit 22, and a line interface 24 for receiving and sending audio signals from and to a calling party via a telephone line (not shown).

Audio processor 18 is conventional in the art and performs various functions under the control of the device control processor 16. For example, audio processor 18 receives audio input signals from microphone 12 and line interface 24. Each of these signals is processed as required by any specific telephone system requirements and stored in message storage 22 in an appropriated format, which format may be analog or digital. Processor 18 further directs audio output signals representing, for example, outgoing messages or messages received from a calling party, to line interface 24 or loudspeaker 20, respectively. Furthermore, audio processor 18 encodes messages such, for example, as voice prompts received from the device control processor 16, into audio signals and sends them to speaker 20.

The device control processor 16 may also be of conventional design. As indicated above, processor 16 controls telephone call processing and the general operation of answering machine device 10. Device control processor 16 receives input from and issues control instructions to speech recognition system 14 and the audio processor 18. Processor 16 also receives input from a criteria selection switch 26. In a manner which will be explained in more detail later, criteria selection switch 26 permits the user to select from among multiple recognition criteria to improve the performance of speech recognition system 14. In response to the input of a user-selection, the device control processor 16 changes the mode of operation of the speech recognition system 14 by sending appropriate instructions, as explained below.

With continued reference to FIG. 1, it can be seen that speech recognition system 14 comprises a conventional analog-to-digital (A/D) converter 28 to convert the audio signal picked up by the microphone 12 into a stream of digital samples; a digital signal processor 30 such as the AT&T DSP 16A, which processes digital signal samples generated by A/D converter 28; a ROM 32, which contains program instructions executed by the digital signal processor 30 (See FIG. 2); a RAM 34, in which temporary computation results are stored; and an HMM parameter memory 36 which is a non-volatile memory such, for example, as a EEPROM, ROM, flash RAM, battery backed RAM, etc. and which, in the illustrative embodiment, contains at least two sets of parameters of hidden Markov models (HMM) for the phrases to be recognized. As will be readily appreciated by those skilled in the art, one or more of devices 28, 30, 32, 34, and 36 may be physically located on the same electronic chip.

Speech recognition system 14 is placed in command spotting mode by a signal from processor 16 indicating that no device control operation initiated by a user is currently pending. In this mode, the system 14 checks each incoming speech utterance from A/D converter 28 for the presence of a command phrase for which one or more HMMs are stored in the HMM parameter memory 36. In other words, in command spotting mode, recognizer 14 employs HMMs in memory 36 which correspond to command phrases such, for example, as "message playback", "record outgoing message", "next message", "rewind", and so on. It will, of course, be readily appreciated by those skilled in the art that HMMs are merely illustrative of the models which may be employed and that any suitable model may be utilized. An utterance from the user is accepted as a command if the presence of such a command phrase is confirmed by the system 14. Otherwise, the utterance is rejected. If the hypothesis is accepted, a signal indicating that a specific command phrase has been detected is sent from speech recognizer 14 to the device control processor 16. Device control processor 16 then initiates the operation associated with the command. If the utterance is rejected, no message is sent to the device

control processor 16. The operation of processor 16 in response to accepted commands is conventional within the art.

With reference now to FIG. 2. there is shown a block flow diagram of the processing performed by the digital signal processor 30 of the speech recognition system 14. Each block represents a distinct processing function which is typically implemented as a subroutine of the program stored in ROM 32. The four basic steps involved in the recognition of speech are: feature extraction, time registration, pattern similarity measurement, and decision strategy. Current speech recognition systems use a variety of techniques to perform these basic steps. Each approach has its own performance and cost mix. The typical speech recognition strategy is to "scan" the incoming speech data continuously, perform dynamic programming, compute a similarity measure or "distance" between the utterance spoken and the stored reference patterns, and decide if the similarity measure is sufficiently close to an anticipated value to declare that the utterance is recognized.

With continued reference to FIG. 2, it will be observed that the speech samples provided by A/D converter 28 are processed by conventional speech extractor 40 to produce a stream of vectors of speech features, typically at a rate of 100 to 200 vectors/second. A variety of signal processing techniques exist for representing a speech signal in terms of time varying parameters which are useful for speech recognition. Examples of suitable signal processing transformations are the direct spectral measurement (mediated either by a bank of bandpass filters or by a discrete Fourier transform), the cepstrum, and a set of suitable parameters of a linear predictive model (LPC) (See J. D. Markel and A. H. Gray, Jr., "Linear Prediction of Speech". Springer-Verlag, New York, (1976)). In the illustrative embodiment of FIG. 2. each vector contains 10 to 30 components of speech features relating to speech energy, delta speech energy, cepstrum coefficients, and delta cepstrum coefficients. The stream of feature vectors is processed by conventional endpoint detector 42 which detector determines the beginning and end points of utterances embedded in the speech. The output of the endpoint detector comprises finite sequences of speech vectors, where each sequence of vectors corresponds to a single utterance.

After feature extraction/end point detection, the next basic recognition step is the computation of a similarity measure between a stored reference and the time-normalized parameters extracted from the utterance. To this end, hypothesizer 43 receives the speech vector sequences output by endpoint detector 42 and generates a hypothesis as to their verbal contents. In so doing, the hypothesizer 43 uses HMM models for the phrases, the parameters of which are stored as indicated by phrase model parameters block 44 and HMM background models, the parameters of which are stored as indicated by background model parameters block 45. The term "background" refers to silence, noise, or any speech which is not one of the command phrases. Physically, all of these models are located in the HMM parameters memory 36 of FIG 1.

Hypothesizer 43 makes two types of hypotheses. The first type of hypothesis (referred to as a "background hypothesis") assumes that the feature vector sequence includes only the background. The second type of hypothesis (referred to as a "phrase hypothesis") assumes that the feature sequence includes a command word, possibly followed or preceded by background. For each of these two hypothesis, the hypothesizer applies a conventional dynamic programming optimization procedure, such as Viterbi decoding (or scoring), which procedure determines the most likely hypothesis of that type and a corresponding numerical value (or score) of the estimated likelihood of the hypothesis.

In addition, the dynamic programming procedure produces some additional parameters for the phrase hypothesis, which parameters are referred to as "match parameters". A first match parameter is generated by forming the difference between an *expected* phrase duration for the most likely phrase hypothesis and the phrase duration determined by the hypothesizer for the utterance corresponding to the most likely phrase hypothesis. A second match parameter is generated by forming the mean of the absolute value of the difference between expected HMM state durations of the most likely hypothesis and the state durations determined by the hypothesizer 43. A third match parameter is generated by forming the difference between the likelihood scores for the most likely hypothesis of the best phrase hypothesis and the second best phrase hypothesis. As will be readily ascertained by those skilled in the art, data for use in generating match parameters is available as part of conventional speech recognition processes employing, for example, HMMs and Viterbi scoring.

The output of the hypothesizer 43 includes the most likely phrase hypothesis; a corresponding score, which is the difference of the logarithms of the phrase hypothesis likelihood estimate and the background hypothesis likelihood estimate; and the match parameters. The verifier 46 receives the output of the hypothesizer 43 and checks if each of the match parameters is within a corresponding prescribed range. The verifier checks whether the first match parameter is within, for example, the range -1/2 to 1. Verifier 46 checks whether the second match parameter is, for example, within a range of 100 ms. Verifier 46 also checks whether the third match parameter is within 10% of the best hypothesis score. (Any of these ranges may be varied to suit particular operating environments). If the match parameter is within the prescribed ranges, the verifier passes the hypothesis and its respective scores to the decision maker 47. Otherwise, the hypothesis is rejected.

The decision maker 47 decides whether to accept or reject the most likely phrase hypothesis. If the hypothesis is accepted by the decision maker 47, the hypothesis is reported to the device control processor 16 of

FIG. 1. The method by which the decision maker 47 makes its decision is explained in the block flow diagram of FIG. 3.

The flow diagram of FIG. 3 begins in step 50 where the hypothesized phrase and its corresponding score are received. In accordance with a simplified embodiment of the present invention, control is directed to block 52 wherein threshold T is set to one of a plurality of fixed values T1, T2, T3, T4, or T5 stored in memory, which may be a RAM 34 or ROM 32. T3 is default value selected, in a conventional manner, to work well for an "average" user in normal conditions. The values of T2 and T1 are selected to obtain an increased likelihood of positive recognition (e.g., 20% and 40% higher probability, respectively, relative to the default setting) at the potential expense of an increase in the number of false positive alarms, while the values of T4 and T5 are selected to obtain a decreased probability of positive recognition (e.g., -15% and -30%, respectively, relative to the default setting) at the potential expense of an increase in missed commands. The value corresponding to the selected recognition criterion is set to T_s and compared to the obtained hypothesis score (block 54). If the score exceeds T_s, the hypothesis is accepted (block 56). If the score is below T_s, the hypothesis is rejected (block 58). As indicated at block 60, the accept/reject decision is then output for use by the device control processor 16 in a conventional manner.

A more sophisticated embodiment of the present invention, a set of thresholds or criteria sets are selected from a plurality of criteria sets, during the operation denoted by block 52, each set of criteria making it ore or less likely, in comparison to a default set of criteria, that a command will be recognized, depending upon the particular set selected. In this regard, it will be noted that HMM word recognition is achieved by computing the likelihood of producing an unknown input work pattern with each of the stored word models, with the input word being recognized as that model which produces the greatest likelihood. The accuracy of the model is influenced by such criteria as the location of the utterance endpoints, duration of the utterance, and the number of frames in each state. IN a conventional manner, each of these criteria may be individually adjusted, in accordance with the selection input by the user, so as to achieve an increased likelihood of recognition, at the expense of more frequent false positive results for the "average user" or a decreased likelihood or recognition, with greater accuracy for fewer users. A default value for each criterion, optimized in a conventional manner to provide the best results for the average user under "normal" environmental conditions, may be utilized in the absence of an input user selection.

By way of additional example, in which telecommunications device 10 is configured as cordless telephone, speech recognition system 14 may be switched from the command spotting mode into a dialing mode by a signal from device control processor 16 indicating that the user has initiated a dialing procedure This dialing procedure might have been initiated by pressing either a keypad button or by saying a command phrase (e.g., "dial") which invokes the dialing operation. In this mode, recognizer 14 uses HMMs of name phrases (instead of command phrases as in the command spotting mode described above), where each name phrase is associated with a corresponding telephone number. Such name phrase HMMs and associated telephone numbers are stored in memory 34. If an utterance of a name phrase is accepted by recognizer 14, a message indicating the recognition of a name phrase has been accepted is sent to device control processor 16. Device control processor 16 then dials the telephone number associated with the recognized name phrase and notifies the user that the name has been recognized correctly. If, however, the speech recognizer 14 rejects an utterance, it nevertheless sends a message to the device control processor 16, indicating that an utterance has been rejected. The device control microprocessor then prompts the user to repeat the utterance. The notification and prompting are typically done by a distinctive tone followed by the audible reproduction of an appropriate voice message.

From the foregoing, it should be readily ascertained that the invention is not limited by the embodiments described above which are presented as examples only but may be modified in various ways within the intended scope of protection as defined by the appended patent claims.

Claims

1. A speech recognizer apparatus (14) for recognizing a phrase including at least one word, based upon an utterance, characterized by:

   a selection module (26) for selecting at least one recognition criterion from one of a plurality of stored classes of recognition criteria, each stored class being associated with a corresponding probability of recognition for a given utterance;
   a comparator module (43), responsive to the selection module, for determining whether the similarity metric corresponding to a most closesly matching model of speech satisfies the selected recognition criterion; and
   a recognizer module (47) for recognizing the utterance as the phrase corresponding to said most closely matching model of speech when the selected recognition criterion is satisfied.

2. The apparatus of claim 1, characterized in that a model of speech reflects one or more predetermined words.

3. The apparatus of claim 2. characterized in that a predetermined word comprises a command word for a utilization device.

4. The apparatus of any of the preceding claims further characterized by a utilization device

5. The apparatus of claim 3 or claim 4, characterized in that the utilization device is a telephone.

6. The apparatus of claim 3 or claim 4. characterized in that the utilization device is an answering machine.

7. The apparatus of any of the preceding claims characterized in that each recognition criterion comprises a threshold and wherein the comparator module is operative to compare the similarity metric corresponding to said most closely matching model of speech to the threshold of the selected set of criteria.

8. The apparatus of any of the preceding claims characterized in that said stored classes of recognition criteria comprises a default class optimized for an average user in normal conditions. at least one class having a probability of recognition greater than said default class. and at least one class having a probability of recognition less than said default class. and wherein said selecting means is manipulable by the user to select one of said recognition criteria classes.

9. A telecommunications instrument (10) including a microphone (12) and characterized by:

   a speech recognizer (14) for recognizing a phrase including at least one word, based upon an utterance. the speech recognizer including a selecting module (26) for selecting at least one recognition criterion from one of a plurality of stored classes of recognition criteria, each stored class being associated with a corresponding probability of recognition for a given utterance:
   a comparator module (43) responsive to the selecting module for selecting, for determining whether a similarity metric corresponding to a most closely matching model of speech satisfies the selected recognition criterion; and
   a device control circuit (16) responsive to recognition of an utterance by said speech recognizer.

10. The telecommunications instrument of claim 10, characterized in that said device control circuit (16) is a telephone circuit for providing telephone operation in response to recognition of an utterance.

11. The telecommunications instrument of claim 9 or claim 10. further characterized by:

   a radio transceiver: and
   an audio processor for interfacing the microphone and the telephone circuit to the transceiver. the audio processor being responsive to control signals provided by the telephone circuit.

12. The telecommunications instrument of any of claims 9 to 11 characterized in that said device control circuit is an answering machine circuit for audibly reproducing stored messages in response to recognition of an utterance.

13. A method of recognizing a phrase including at least one word, based upon an utterance. the method characterized by the steps of:

   comparing the utterance to one or more speech models to determine a similarity metric for each such comparison:
   determining, in a first determining step. which model of speech most closely matches the utterance based on the one or more similarity metrics obtained during said comparing step:
   selecting at least one recognition criterion from one of a plurality of stored classes of recognition criteria. each stored class being associated with a corresponding probability of recognition for a given utterance:
   determining, in a second determining step. whether the similarity metric corresponding to the most closely matching model of speech satisfies the selected recognition criterion: and
   recognizing the utterance as the phrase corresponding to said most closely matching model of speech when the selected recognition criterion is satisfied.

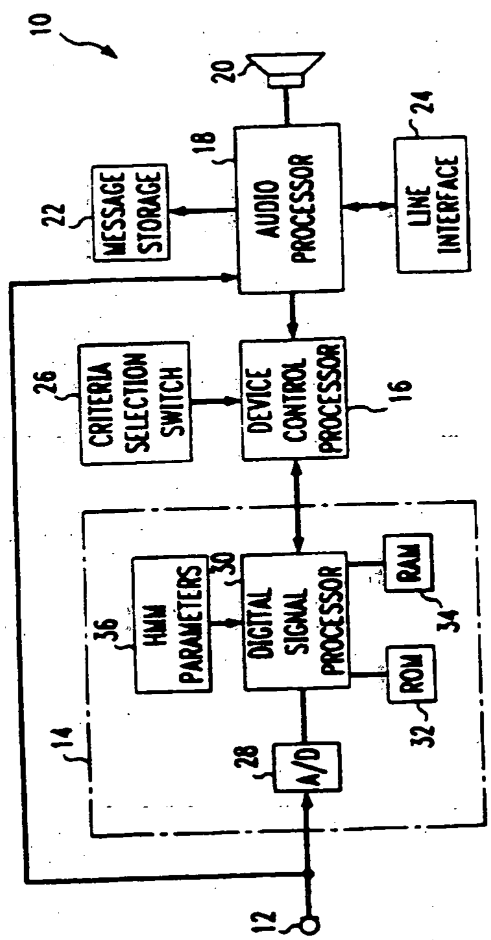

10
12
14
16
CRITERIA SELECTION SWITCH
26
DEVICE CONTROL PROCESSOR
18
AUDIO PROCESSOR
20
22
MESSAGE STORAGE
24
LINE INTERFACE
28
A/D
30
DIGITAL SIGNAL PROCESSOR
36
HMM PARAMETERS
32
ROM
34
RAM

FIG. 1

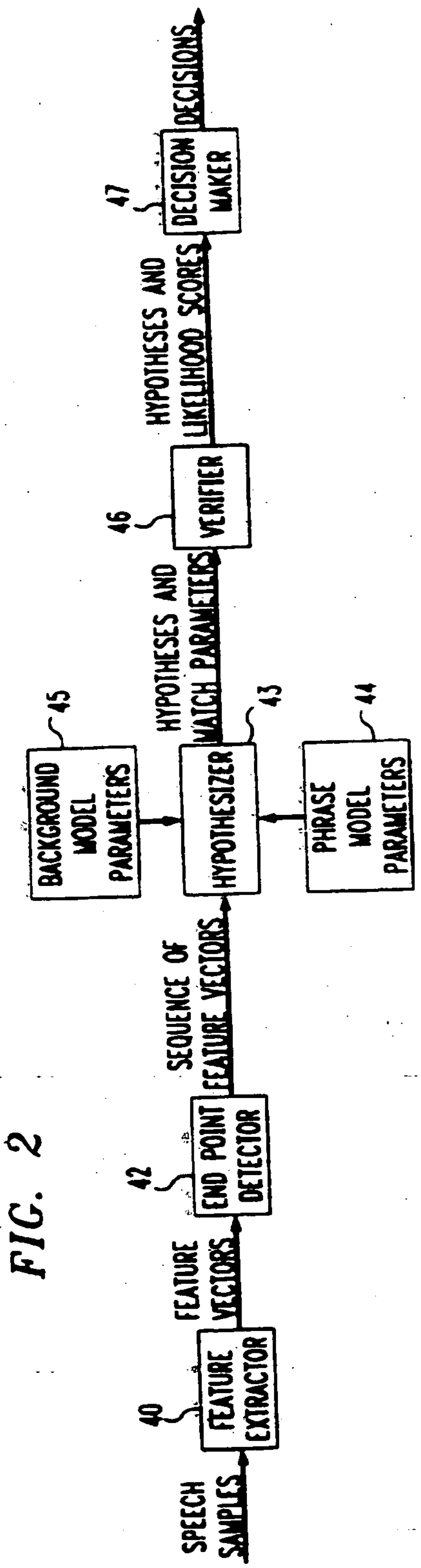
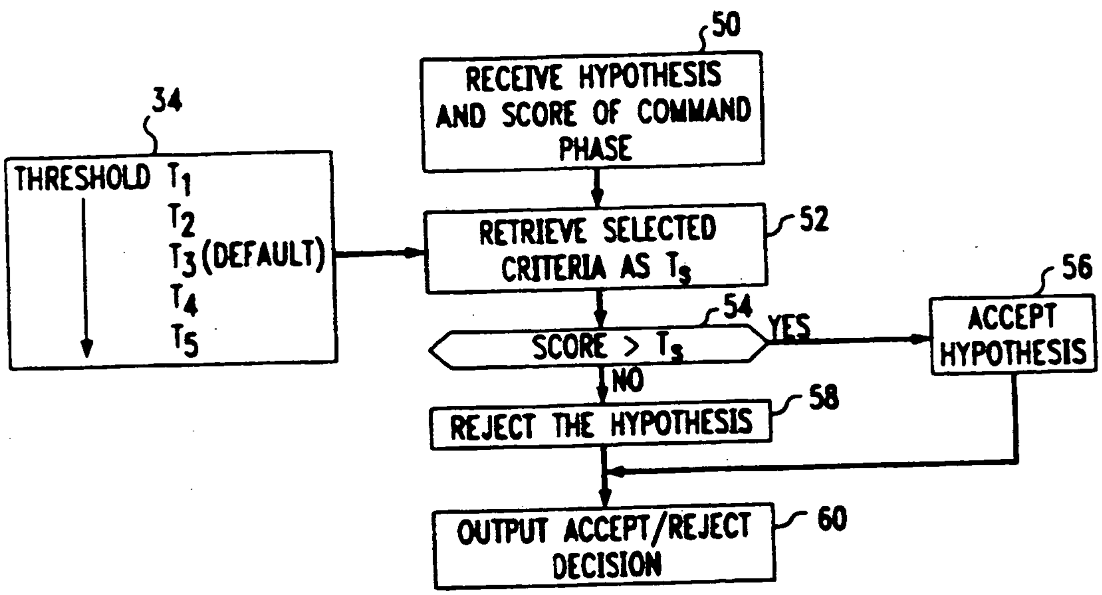

SPEECH SAMPLES
40
FEATURE EXTRACTOR
FEATURE VECTORS
42
END POINT DETECTOR
SEQUENCE OF FEATURE VECTORS
43
HYPOTHESIZER
44
PHRASE MODEL PARAMETERS
45
BACKGROUND MODEL PARAMETERS
HYPOTHESES AND MATCH PARAMETERS
46
VERIFIER
HYPOTHESES AND LIKELIHOOD SCORES
47
DECISION MAKER
DECISIONS

FIG. 2

FIG. 3


50
RECEIVE HYPOTHESIS AND SCORE OF COMMAND PHASE
34
THRESHOLD T_1
T_2
T_3 (DEFAULT)
T_4
T_5
RETRIEVE SELECTED CRITERIA AS T_s
52
56
54
SCORE > T_s
YES
ACCEPT HYPOTHESIS
NO
REJECT THE HYPOTHESIS
58
OUTPUT ACCEPT/REJECT DECISION
60